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TITLE PASSIVE SOLAR APPLICATIONS

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PASSIVE SOLAR APPLICATIONS*

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ABSTRACT

Passive solar applications in buildings are described. The major emphasis of the research has been on devising mathematical models to characterize heat flow within buildings, on the validation of these models by comparison with test results, and on the subsequent use of the models to investigate the influence of both various design parameters and the weather on system performance. Results from both test modules and monitored buildings are discussed. Simulation analysis, the development of simplified methods, and systems analysis are outlined. Passive solar potential in China is discussed.

INTRODUCTION

Passive solar buildings collect, store and distribute energy from the environment using only the processes of radiation, conduction, and convection. Passive solar heating is accomplished by admitting winter solar radiation primarily through south facing glazing, storing this heat within the inherent mass of the building and distributing the heat by radiation and convection. Natural cooling techniques reject heat from the building by radiation to the sky, by natural ventilation, and by evaporation of water when these mechanisms can be effective, which is often at night.

For these natural mechanisms to be at all adequate it is vitally important to reduce the magnitude of the heating or cooling energies using conservation techniques. In the winter, this means the effective use of insulation placed outside the thermal mass of the building and the reduction of air infiltration. In the summer, this means reducing the solar gains into the building, which is most effectively achieved by shading, especially on the east and west sides of the building, by insulation, and by low-emittance radiant barriers within walls or attic spaces. A particularly effective passive solar strategy in all seasons is the use of sunlight during the day (daylighting) to reduce the need for artificial lighting.

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Passive solar is inherently an architectural approach to achieving building comfort. Success is achieved not so much by the use of new materials but by the architectural configuration of normal building materials into geometries which are effective. Orientation of most of the windows on the south side of the building is essential. The use of Trombe walls, water walls, or sunspaces on the south side can also be very effective, especially in balancing the daytime and nighttime delivery of heat to the building. Placement and design of window openings to provide effective daylighting and adequate summer ventilation must be carefully planned. In contrast to active solar methods, in which a mechanical system is added to the building, in passive solar design the architecture is the system. Economy is achieved by the multiple use of building components. The result, properly executed, is not only a reduction in heating and cooling energy, but an inherently more comfortable and reliable building.

Although passive solar applications in buildings have been extensively practiced by several different civilizations over the period of human history, modern interest in passive solar heating is quite recent, starting in the early 1970s. The number of passive solar installations has grown incredibly from a half-dozen to well over 200,000 in 10 years; although most are located in the United States, we are now seeing major interest developing in many other countries throughout the world. It is certainly conceivable that within 10 years most new construction will utilize passive solar techniques for a significant part of their heat and employ some natural cooling techniques.

RESEARCH DIRECTIONS

The main focus of research in passive solar heating has been on the performance evaluation of buildings. Knowledge gained through the understanding of the behavior of existing buildings can be used both to predict the performance of future buildings and to devise strategies to make them more effective. Thus, a major emphasis of the work has been threefold: (1) development of mathematical models that characterize heat flow and thus thermal behavior, (2) the validation of these models by comparison with test results, and (3) the subsequent use of the models to investigate the influence of both various design parameters and weather characteristics on performance.

This explanation illustrates how analytical modeling work has become the cornerstone of the research effort. This relationship is shown clearly in the schematic diagram of Fig. 1, which shows the key elements of the research program and the relationship between those elements. The logical progression of activity flows from left to right in this schematic, beginning with experimental results obtained in test modules, special experiments, or monitored buildings. Based on these results and known physical principles, analytical models are developed and validated. Using weather and solar data from a particular locality, the analytical models can then be used to predict performance in a variety of climates for a variety of proposed designs. The models can also be used for sensitivity analyses, to develop simplified prediction methods, and to explore the relationship between passive solar and conservation strategies. Results are published both in technical papers and as user-oriented manuals.

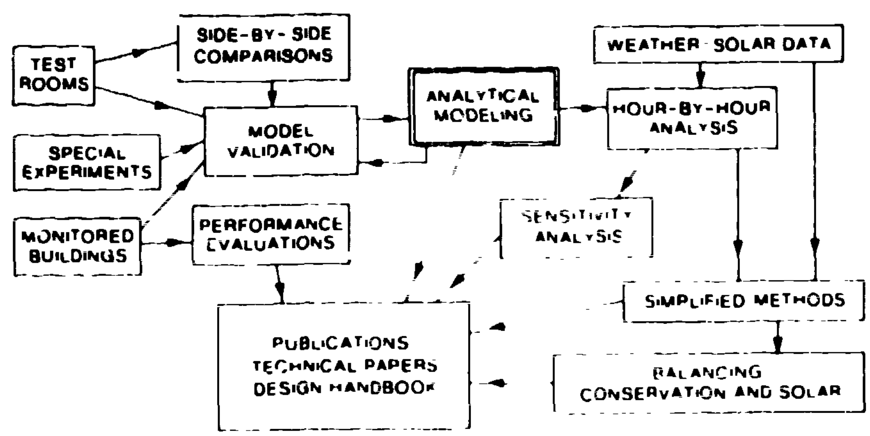

Fig. 1 Schematic of the key elements of the research program.

EXPERIMENTAL RESULTS

Test modules

Small test modules play an important role in passive research. Quite a large number of special-purpose test modules have been built to obtain data under carefully controlled conditions. Efforts in the U.S.A. are reviewed by Moore and McFarland [1]. The units serve three major purposes as follows:

(1) Direct side-by-side comparisons of various competing strategies.
(2) Obtaining data for the validation of computer codes.
(3) Special component tests.

Test modules are sometimes operated free running, that is, without auxiliary heat. More commonly, they are operated with a thermostatically controlled inside environment. This allows a more direct comparison between units and yields a more realistic operating profile.

Three sizes of test units have been built: test boxes, usually about 1 m on a side; test rooms, usually about $4 m^2$ in area; and larger test buildings, which may have more than one room.

Monitored Buildings

Numerous passive solar buildings have been monitored by various researchers with generally encouraging results. The general conclusions from a study of these monitored buildings are as follows:

• Building heat load coefficients in the range of 0.83 to 1.53 $W/^{\circ}C m^2$ are routinely achieved, although much larger values are observed for a few buildings. The results underline the importance of good conservation practice.

• Auxiliary heating requirements as low as 0.24 to 0.48 $W/^{\circ}C\ m^2$ in sunny climates are achievable. Values of 1.5 times these levels are routinely achieved.

• Internal heat varies widely and, in some cases, makes a major contribution.

• Solar fractions of 50% or greater are often achieved. In some cases the solar performance is illusory because losses from the glazing probably equal or exceed solar gains. It is estimated that the solar savings exceed 50% of the total load in about one half of the buildings.

• Other benefits should also be considered. For example, the daylighting reduces the need for artificial lighting by about 60%. This explains the moderate internal heat observed in most cases.

• Proper site selection and passive collector orientation are very important to good performance. Some systems demonstrating the worst performance are those that are sited incorrectly.

• No particular passive system type emerges as the best performer. Good thermal design, however, is essential.

MATHEMATICAL MODELING

Performance prediction, based on sound physical principles, is essential if passive solar heating is to develop in an orderly fashion. Research results combined with practical experience will merge into design tools that are simple to use but comprehensive enough for widespread application. Intuition plays an important role in the evolution of new concepts, but it is only through the application of scientific techniques that research can sort out wishful thinking from sound and effective methods.

Simulation using thermal networks

The response of a building to any schedule of heat input is simulated by solving a set of differential equations that describe the heat flow from point to point within the building. One must first select a reasonably small set of elements within the building whose temperatures will be calculated. Elements that can be expected to be about the same temperature can be lumped together into one element. It is of particular importance to include all of the important heat-storing mass within the building in one or another of these mathematical elements. Massive portions expected to be at rather different temperatures should be characterized as different elements.

Having made this selection, the analyst then writes an ordinary differential equation describing the heat balance for each element. This heat balance includes heat flow to neighboring elements by radiation, conduction, or convection, solar energy inputs, and other heat inputs. This set of differential equations can then be solved as an initial value problem with several independent variables including solar gain, outside temperature and thermostat setting. Auxiliary heat input is adjusted to maintain a desired temperature of one or more of the elements (the room air temperature is usually the controlled element).

Simplified methods

It is now generally accepted that computer simulation will give an accurate representation of the performance of passive solar buildings, a condition that makes simulation a desirable design tool if the designer has the equipment, the capability, and the inclination to take this approach. But even under the best of circumstances, it is costly and time consuming. Most designers ask for simpler techniques that are amenable to the use of hand calculators or desk-top microcomputers on which estimates can be generated in a few minutes.

Correlation techniques that meet these requirements and give reasonable accuracy have emerged as practical procedures. These methods are particularly useful early in the design process when quick feedback is essential; they can be applied to either residential or commercial buildings. Both a monthly calculation--the solar load ratio (SLR) method--and an annual calculation--the load collector ratio (LCR) method--have been developed. The annual method uses tables precalculated by the SLR techniques and is more appropriate to hand anaylsis, whereas the monthly method is more versatile and is more appropriate to programmable calculator or microcomputer-aided analysis [2].

Systems analysis

Systems analysis includes four types of analytical investigations: the first is the systematic study of how climate affects passive solar heating performance, the second is the study of how changes in design parameters affect system performance in a particular locality, the third is the development and use of correlation techniques as a simplified method of performance estimation, and the fourth is the development and use of a methodology for determining the optimal mix between conservation and solar strategies.

PASSIVE SOLAR POTENTIAL IN CHINA

The following observations are based on the author's very limited observations around the northern Chinese cities of Beijing and Lanchow. Based on experience in other parts of the world it is predicted that passive solar heating and natural cooling can find many applications throughout this large country with its many diverse climates. In particular it is expected that in the relatively arid and sunny regions of northern China, in which winters are long and cold, that passive solar heating will be very appropriate.

Traditional residential architecture already makes some use of passive solar heat. Building orientation and form are usually correct, i.e., long in the east-west direction, and short in the north-south direction, with primary glazing on the south side. Effective use is made of wing walls and courtyards to provide a sheltered area to the south of the building. Trees, vegetation and double roofs are effectively used for summer shade. Larger buildings almost always make effective use of daylight. Compared with most other countries, China has a good head start on passive solar.

What is needed in order to make more effective use of passive solar is to enhance the existing traditions rather than to make sweeping changes. Two materials are critically important to the success of this effort: building insulation and glazings, both of which can be readily produced within China. Insulation should be placed outside the building mass and then suitably protected from the weather, perhaps by a cement plaster coat. This will allow the building to store and retain passive solar gains. Glazings are essential to admit and retain solar gains. Glass is excellent but is expensive and fragile. Perhaps appropriate polymeric glazings, such as multi-layer acrylics, can be economically manufactured to be durable, resistant to ultraviolet degradation, have good solar transmission, and low heat loss. Use of both these materials would be equally applicable to the retrofit of existing buildings and to new construction.

Research is needed, not only in materials, but in the most appropriate use of the various passive solar strategies in different building types. No one solution or formula will be valid throughout the country. Traditional regional architectural styles should be respected and studied to learn whether they already make effective use of passive solar heating or natural cooling and how they might most economically be modified to be more comfortable. Test modules, test rooms, and test buildings can be used to gain experience and confirm predictions. Mathematical modeling can be used to try out new ideas before construction, to optimize performance, and to develop general guidelines for various climates.

Passive solar has major implications not only to human habitations but also to warm livestock shelters and to enhance and prolong the growing season in greenhouses. It should be quite possible and practical to achieve the desired results without the use of any auxiliary energy. The potential for a country that is predominately rural is very great. One possibility is the use of well designed sunspaces attached to the south side of houses to increase the house comfort, provide extra living space, and allow the growing of vegetables throughout the winter.

REFERENCES

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